Modified tree structure for location management in mob environments

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Abstract:
Suggests a new data structure for location management in mobile networks. Th structure is based on the tree location database structure. The authors suggest the root and some of the higher levels of the tree with another structure that ba average load of search requests. For this modification they use a set-ary butter network, which is a generalization of the well-known k-ary butterfly. They also modifying the lowest level of the tree in order to reflect neighboring geographic more accurately and to support simple location data management. The modific lowest level also supports simple handoffs. The update of the proposed location ensures correct location data following any number of transient faults that corr location database information and thus is self-stabilizing.

Index Terms:
tree data structures; computer network management; data communication; lan radio; tracking; location management; mobile environments; modified tree str data structure; tree location database structure; root; search requests; set-ary network; k-ary butterfly; neighboring geographical regions; location data man handoffs; transient faults

SEARCH RESULTS PDF FULL-TEXT PREVIOUS NEXT

Comparative benefits of various automotive navigation a routing technologies

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Index Terms:
automobiles; navigation; Global Positioning System; cartography; visual datab real-time systems; geographic information systems; automotive navigation; au location; dead reckoning; digital map-matching; Global Positioning System; di GPS; map databases; directionality; route-guidance

SEARCH RESULTS PDF FULL-TEXT PREVIOUS NEXT

Comparative Benefits Of Various Automotive Navigation And Routing Technologies

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Abstract -- The first practical in-vehicle automotive navigation systems (introduced in 1985) utilized dead reckoning combined with digital map-matching to keep track of vehicle positions and to show them in real time on digital map displays. Dead reckoning was based on wheel sensors and a magnetic compass, and map-matching was based on extremely accurate digital maps. Routing to destinations was based on vector navigation -- an arrow and number indicating the bearing and great-circle distance to a selected destination. Dead-reckoning-and-map-matching technology has advanced considerably during the decade of its development. Not only has digital map accuracy, coverage, and completeness improved, but gyroscopes and electric odometers have simplified installation of dead-reckoning systems. Global Positioning Satellites (GPS) and differential GPS have provided significant navigation system improvements when combined with dead-reckoning, and they have enabled alternative navigation systems that operate without dead reckoning. The introduction of map databases with accurate connectivity, directionality, and turn-restriction attributes have permitted automatic computation of optimum routes as well as presentation of turn-by-turn route-guidance instructions for driving those routes. All of these technologies have advantages and limitations relative to features, performance, accuracy, reliability, and cost. Satisfactory systems for widespread commercial and consumer applications require combinations of techniques to provide attractive features and acceptable performance. This paper describes advantages and limitations of various automobile location and routing techniques, and discusses how limitations can be overcome by combining techniques. Tradeoffs between features, performance, and cost are also presented for some specific implementations.

Introduction

A variety of vehicle location and tracking technologies are being utilized for Intelligent Transportation Systems (ITS) applications such as Automatic Vehicle Location (AVL), Computer Aided Dispatch (CAD), and vehicle navigation and routing. The principal technologies being employed include dead reckoning, map matching, global positioning satellites (GPS), differential GPS (DGPS), radio-transponders, or various combinations of these techniques. Considerable effort is being expended in ITS to provide drivers with real-time information about traffic incidents, congestion, and other events, and to furnish "optimum" routing that can minimize travel time.

Many of these applications and technologies are required to locate a vehicle, to correlate its position with the road network, to show its position on a map, and to direct its driver to a destination. In order to show the vehicle at the proper position on the correct road implies specific levels of relative and absolute accuracies both for the position sensors and for the maps used to interpret vehicle locations. Optimum routing applications also place stringent requirements on the accuracy and timeliness of vehicle positioning, real-time information, and map-databases. These required accuracies depend somewhat on the particular application and on the technologies employed.

This paper will describe vehicle location, routing, and digital map technologies, their relative and absolute accuracies, and their suitability for various applications.

Background

When Etak introduced the first automotive in-vehicle navigation system in 1985, navigation was accomplished by a combination of dead reckoning and map matching (DRAMM). The dead reckoning sensors consisted of a magnetic compass (to measure vehicle heading) and wheel rotation sensors on the two undriven wheels (to measure distance traveled and turning information). Map matching was based on the assumption that if a vehicle traveled a reasonable distance at a reasonable speed it must be on a road. Hence, lateral-position errors and heading errors could be corrected based on known road positions and road headings, and distance-traveled (longitudinal position) errors could be corrected each time the vehicle went around a curve or turned a corner onto a known street.

Dead reckoning with map matching obviously places accuracy requirements on both the dead-reckoning sensors and on the digital road maps. The error in dead reckoning is, on average, about 2% of the distance traveled [1]. Road map positional accuracies are needed that are better than 15 meters absolute and 5 meters relative. It was the general lack of road maps in digital form, and the particular lack of

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positionally accurate road maps in any form, that led to Etak's present primary business of providing highly accurate digital road maps and related software.

Today, map matching software has been refined to a degree whereby dead reckoning with map matching works incredibly well. Literally thousands of in-vehicle navigation units based on the original Etak technology are in operation today. They are used in ambulances, fire trucks, delivery vehicles, and private cars for automatic vehicle location (AVL), computer aided dispatch, navigation, destination finding, and route guidance. When operating properly, DRAMM can provide vehicle location accuracies to better than 15 m absolute and 5 m relative.

System Shortcomings

In spite of working extremely well most of the time, these dead-reckoning systems are subject to occasional mistakes whereby the vehicle's position will be shown off the road or on an adjacent road. These mistakes are easily corrected by the vehicle operator with simple manual intervention, and are therefore not a serious problem for professional users. Although infrequent -- perhaps one occurrence for every 200 miles driven [1] -- such mistakes can be a source of user annoyance in consumer applications.

Dead-reckoning navigation errors can be caused by a variety of real-world factors. Probably the least reliable information in the DRAMM systems described above comes from the magnetic compass. It is not the compass itself that is at fault, but rather anomalies in the earth's magnetic field. These anomalies can be caused by steel reinforcements in elevated roads and overpasses, by steel enclosed bridges, by trolley tracks in the roadway, or by other metallic objects in, under, or near the road. Such magnetic anomalies can produce errors in measuring vehicle heading, and can result in the DRAMM system following the wrong road, particularly at intersections where the roads branch apart from one another at relatively small angles.

Since both undriven wheels on a vehicle are usually equipped with sensors, differential wheel rotation can be used to give some sense of vehicle turning and therefore changes in vehicle heading. This information can be used to compensate for the compass errors created by magnetic field anomalies over short distances, but it is not accurate enough to completely overcome the problem for magnetic anomalies distributed over long distances.

Another type of navigation error can be caused by accumulated wheel sensor errors. Some highways and interstate freeways are extremely straight for 100 or even 200 kilometers. A 2% error in distance measurement can then amount to 2 to 4 kilometers error in position along the road so that when the road finally turns or when the vehicle exits the freeway onto another road, the map matching may judge the vehicle's position to be off the road or on a road that is adjacent to the actual road. In general, positional accuracies must be maintained to 15 meters or better to avoid these sorts of problems when using DRAMM.

Global Positioning Satellites (GPS)

The introduction of the Global Positioning Satellite (GPS) system and the ready availability of GPS receivers has provided another means for vehicle location and in-vehicle navigation. Unfortunately, intentional GPS positional errors are introduced by the U.S. Department of Defense for National Security reasons, and these errors limit the normal vehicular positional accuracies attainable with GPS to about 100 meters. This "feature" is called Selective Availability (SA). These intentional errors are random and tend to slowly drift around within a 100-m radius circular area centered on the true GPS receiver position. The rate of drift exhibits a quasi period on the order of 5 to 10 minutes. The 100-m accuracy is not sufficient for many AVL and in-vehicle navigation applications because a 100-meter error can easily indicate a vehicle on the wrong road in many situations such as a dense urban street network or where a frontage road runs adjacent to a highway. Furthermore, GPS signals are subject to outages caused by screening of the satellites from a vehicle's GPS receiver by buildings, hills, or dense foliage. GPS position errors can also be produced by multipath from nearby structures and terrain.

Combining GPS with DRAMM has been shown to largely overcome the weaknesses of each approach used independently [1]. In the combined approach, GPS information is used to initialize the system and to update vehicle positions when dead reckoning and map matching are in poor agreement, thereby indicating that the present map-matching position may be incorrect. In that case the estimated vehicle position is adjusted to the GPS position which is usually close enough to the actual vehicle position that the map matching can subsequently acquire the true position and compensate for the GPS errors. If the present GPS error is too great for the map matching to acquire the true position, then additional GPS updates are made to take advantage of the random drift in GPS errors until the map matching is able to acquire the true position. This approach -- which is really a DRAMM system augmented by GPS -- uses GPS to correct for those occasions when DRAMM is in error. It thereby achieves much better accuracy and continuity than attainable with regular GPS by itself while it provides self-correction for the DRAMM errors that occasionally occur.

Differential GPS

Another GPS technique now coming into increasing use is Differential GPS (DGPS). DGPS uses a fixed GPS

receiver of known location to measure the errors introduced by SA. These measured errors can then be used to correct (i.e., remove SA errors from) GPS positions that are measured on mobile platforms in the vicinity. The corrections can be communicated to mobile vehicles for improved performance of in-vehicle navigation systems, or they can be applied at central facilities such as dispatch centers to correct AVL position indications there.

Positional accuracies obtainable with DGPS are generally better than 10 meters. That accuracy in itself would be sufficient for vehicle navigation if it were not for the practical shortcomings of DGPS caused by signal dropouts and multipath. Signal dropouts of both the satellite signals and the differential correction communication signal are caused by screening from structures, terrain, and dense foliage. In addition, multipath caused by satellite signal reflections from nearby structures and terrain can produce errors in the mobile GPS positions that are not compensated for by differential corrections.

These problems are more common than might be expected. GPS signals generally cannot be received at all inside tunnels and suspension bridges, for example. Accurate DGPS navigation requires that three and preferably four or more GPS satellites must be in view at all times. Screening and multipath from tall buildings are especially acute in large cities where it is frequently difficult to get clear views of three or more satellites simultaneously. Dropouts of the differential corrections signal can occur for the same reasons. While some AVL and in-vehicle navigation applications may not require continuous vehicle tracking, those applications that do require dead reckoning systems combined with DGPS in order to overcome signal dropouts.

An interesting issue is whether or not DGPS navigation systems with dead reckoning will also require or benefit from map matching. The answer probably depends on the application. Most consumers expect that in-vehicle navigation systems with map displays will show the vehicle position in the correct position exactly on the proper road. DGPS with dead reckoning can track the vehicle position to better than 10 meters in most circumstances, which is certainly accurate enough for display purposes. Remember, however, that the absolute accuracy of the underlying digital road map is about 12 meters. Consequently, DGPS vehicle positions may, at times, appear to be off the road by up to 22 meters. This discrepancy may not be objectionable or even noticeable for most map display levels. However, when zoomed in to the most detailed scales, the vehicle's position may appear far enough off the road to be objectionable, and map matching may therefore be desirable for aesthetic reasons.

A more important reason for maintaining map matching even with DGPS in-vehicle navigation systems is that differential correction signals are not yet (and may never be) universally available, particularly in rural areas. Depending on the technology utilized to communicate DGPS corrections. While it is practical and likely that sufficient numbers of fixed GPS stations will be provided to cover major metropolitan areas, it seems less likely that the same will be true in remote and rural areas.

There are already several commercial services providing differential correction signals via FM radio station subcarriers and via direct satellite transmission. The U.S. Coast Guard is also broadcasting GPS differential correction data around coastal regions and major waterways for mariners, and there are plans for the FAA to broadcast differential corrections for aircraft. Consequently, it seems likely that differential correction signal services will be readily available for ground navigation at least in major metropolitan areas within the next few years. In rural areas, however, differential corrections data at ground level may be unavailable due to low signal strength from terrestrial radio transmissions as well as due to foliage and terrain screening of satellite transmissions. Hence, map matching may be required in remote areas not only for aesthetic reasons, but for reliable navigation. In-vehicle-navigation systems that work reliably on cross-country trips in remote and rural areas as well as in metropolitan areas are likely to become an important application for map matching technology.

Other Sensors

As mentioned previously, the magnetic compass and wheel sensors used for dead reckoning are not as accurate and dependable as desired. In addition, wheel sensors tend to be a maintenance liability because they are subject to damage by snow, ice, loose gravel, and other road hazards. Installation of the wheel sensors and magnetic compass can be difficult and moderately expensive operations, particularly for after-market applications. Alternative sensors are desirable. Etak and other companies have been evaluating additional sensors and combinations of sensors that might reduce the installation and maintenance costs and improve the performance of dead reckoning.

A system tested by Etak most recently utilizes a gyroscope (to get vehicle turning information), an electrical tap to the vehicle's existing odometer (to get distance information), and a GPS receiver (to get heading and position information). The installation is greatly simplified by this approach, and reliability and maintenance are clearly improved. Navigation performance is comparable to previous DRAMM systems. While the problems with the magnetic compass were eliminated, similar problems occur when GPS heading information is lost because of GPS dropouts. The turning information provided by the gyroscope is an adequate alternative to that provided by differential wheel sensors.

OTHER AVL AND NAVIGATION TECHNIQUES

A variety of other AVL and navigation techniques have been proposed and/or tested by various workers. The suitability of each technique depends substantially on the specific application.

One very successful AVL technique being deployed by Pactel Teletrac uses inexpensive vehicle radio transponders that can be tracked from radio towers on hills surrounding metropolitan areas using time-difference-of-arrival (TDOA) techniques. Each transponder provides a unique code for positive vehicle identification. Positional accuracies reported are typically 300 meters or better, and applications include fleet vehicle tracking and stolen vehicle recovery.

Other systems use electronic benchmarks and signposts near the road which passing vehicles can use to electronically determine their precise locations and through which vehicles can transmit and receive information. These systems have the advantage that the in-vehicle navigation and information devices can be relatively simple, in exchange for increased complexity in the infrastructure.

NAVIGATION AND ROUTING APPLICATION REQUIREMENTS

A majority of navigation and routing applications make use of digital maps and other geographic databases such as digital directories which include yellow pages, travel guides, and hotel and restaurant guides. The applications and importance of geographic databases to these and other ITS applications are described below.

Geographic Databases

Two types of geographic databases will be discussed here: digital maps and digital geographic directories. While distinctly different in composition and structure, both types serve important functions in ITS applications.

Digital Maps: Digital maps come in two types: scanned-map images and vector maps. Scanned maps are simply digital bit-map images of paper maps that can be displayed by computers. Scanned maps have the advantages that they can be easily produced from paper sources, they can provide all of the information contained in the original sources, and they generally have the familiar appearances of the paper maps from which they are derived.

Vector maps, on the other hand, consist of the basic topological information needed by a computer to draw maps. Vector maps are comprised of:

- nodes (e.g., points where two roads cross) which carry attributes such as latitude, longitude, and connectivity (i.e., what maneuvers are possible)
- lines (e.g., the road segments between nodes) which carry attributes such as road classification (type) and directionality, and
- polygons (e.g., the areas enclosed by lines) which carry attributes such as street address ranges, city, Zip code, etc.

Vector maps have significant advantages over scanned maps for ITS applications because they require less storage, they provide faster access, they are more flexible and easy to manipulate, and they are relational in that the associations between various map elements are implicit in the data structure. The latter advantage is especially significant, because it permits some of the most important ITS functionalities such as:

- destination finding from street addresses or street intersections,
- automatic pathfinding and route guidance (finding and showing the best route) from an origin to a destination, and
- map matching to correct for navigation sensor errors.

Vector map databases are themselves generally available in a variety of format types including: (1) industry standard ASCII interchange formats that are directly useable by most GIS systems, (2) industry standard application formats such as NRA used in many automotive navigation systems, and (3) highly-compressed rapid-access proprietary formats that can reduce storage requirements by a factor of 10 and access times by a factor of 100 compared to industry standard interchange formats.

Digital Geographic Directories: As mentioned previously, digital geographic directories include databases such as yellow pages, white pages, landmarks, travel guides, and hotel and restaurant guides. They can contain the usual information expected in such directories such as classified business listings, hotel and restaurant reviews, lists of tourist attractions, descriptions of things to do, entertainment guides, and related information such as addresses, phone numbers, hours of operation, and so forth. Being classified and in digital form permits computer searches on, for example, business type (such as restaurant or hotel), subtype (such as Japanese cuisine), and features (such as an excellent view or fast service).

Digital geographic directories have another very important attribute -- the geographic location (latitude and longitude) is provided for each listing in the directory so that computer searches can be based on geographic location and proximity as well as on other attributes. Hence, searches could be made for the nearest hospital to the present location, for all of the hotels within a kilometer of the convention center, or for the five parking lots closest to the theater. The ability to perform geographic searches and to select listings based on proximity is a remarkably useful

property. To speed up searches, listings are sometimes presorted into geographically related subgroups. Each member of the same subgroup is then assigned the same grid-key index (in addition to its latitude and longitude). Thereafter, only those listings having the proper grid-keys need to be considered when searching for listings with other specific attributes.

Digital geographic directories provide a very convenient means for finding destinations with ITS products and services. Since each listing is already geocoded with its latitude and longitude, the direction and distance to a selected listing can be easily calculated given the latitude and longitude of an origin.

NAVIGATION, ROUTING, AND OTHER APPLICATIONS OF GEOGRAPHIC DATABASES

There are many applications for geographic databases in ITS. A few examples where geographic databases are most crucial to ITS include automotive navigation, fleet management, traveler information systems, and emergency notification systems. These general applications will be presented in this section. Some Operational Tests to demonstrate and to evaluate such applications will be described in later sections of this paper.

Automotive Navigation

Presently available automotive navigation systems span a wide range of features and capabilities. The simplest devices (such as the Delco Telepath 100) provide vector navigation only. A GPS receiver tracks the present vehicle location, and menus provided via a simple text interface are used to select destinations from digital geographic directories. The display then continuously indicates the great circle direction and distance to the selected destination from the present location, allowing the driver to "home in" on the destination. The geographic directories may include classified yellow pages and tourist guides that list hotels, restaurants, medical facilities, airports, and other businesses, services and attractions. White page directories can also be included so that destinations can be selected from street addresses or from street intersections. Notice that this class of navigation system does not employ digital maps at all -- only digital geographic directories. Of course, digital maps are used in the production of the digital geographic directories.

A more complex type of automotive navigation system (such as the Sony NVS-F160) combines vector navigation with moving-map displays presented to the driver with a graphical computer display mounted on or near the vehicle dashboard. GPS indicated position is shown on the map display and destinations can be selected from tourist guides, hotel and restaurant guides, street addresses, street intersections, or locations entered on the map display. In addition to symbols showing the destinations on the map display, a number and an arrow on the display indicate the great-circle distance and direction (relative to the present vehicle heading) from the present location to the destination. Hence the driver can use the map display to choose possible roads to the destination as well as utilizing vector navigation to "home in" on the destination. These map-display vector-navigation systems use digital map databases for navigation and map display as well as using digital geographic directories for destination finding. The map databases include landmarks, street names, and road classifications in order to provide informative, uncluttered displays at all zoom levels.

Full-featured navigation systems (such as the Clarion NAX-9100) add pathfinding and route guidance to the functions described above. They incorporate digital geographic directories for destination finding, and they utilize digital maps combined with GPS, dead reckoning, and map-matching to track the present vehicle position. Many, but not all, use digital maps to provide map displays. The most significant enhancement of the full-featured systems is that they provide pathfinding and route guidance. Pathfinding automatically calculates the "best" route (e.g., shortest or fastest) from the present location to the selected destination. Route guidance provides turn-by-turn instructions for driving to the destination from the present location. Route guidance may be provided by a highlighted path on the map display, by arrows indicating maneuvers on intersection diagrams, by text instructions, by voice prompts or by a combination of these features. Map databases for pathfinding and route-guidance systems must include nearly flawless data on road connectivity, one-way streets, and turn restrictions (e.g., no left turn). Many systems also require sign information so that drivers can be provided text and voice instructions that are consistent with roadway exit and information signs.

Fleet Management

Fleet management systems use digital maps in dispatch centers to keep track of the locations of vehicles. These Automatic Vehicle Location (AVL) systems use various techniques including GPS, automotive navigation systems, or navigation benchmark systems to track vehicle locations. Such systems are presently in operation in ambulances, fire trucks, buses, paratransit, and commercial fleets, and have been shown to significantly increase operating efficiency, effectiveness, and safety. In some cases automotive navigation systems with digital map displays are provided in the vehicles so that drivers can see their present locations and destinations displayed on a map and can thereby find their destinations as quickly as possible. This capability is especially important to ambulances, fire trucks, delivery

vehicles, and door-to-door passenger shuttle services. Digital geographic directories are also useful to both drivers and dispatchers for finding destinations from addresses, street intersections, and yellow pages.

Traveler Information

ITS traveler information is provided through a variety of mechanisms in addition to automotive navigation systems. Current examples which utilize both digital maps and digital geographic listings include software applications for home, office, and portable computers (including PDAs); kiosks in public places such as transportation terminals and building lobbies; and on-line computer services. Interactive television services utilizing geographic databases will be available in the near future. These traveler-information products and services can provide most of the features described for automotive navigation systems including destination finding, pathfinding, and route guidance instructions.

A rapidly emerging addition to the traveler information features described above is real-time information on traffic, weather, road conditions, special events, bus positions, and other useful information. The information can be delivered on-line for home and business applications or wirelessly to portable and automotive devices. Such information is often provided and presented with the aid of digital maps. Path-finding and route-guidance applications can use such real-time information to calculate optimum paths dynamically in order to compensate for new traffic incidents or other changing road conditions.

Emergency Notification

Another important ITS application that benefits greatly from digital maps is that of Emergency Notification or "Mayday" services. For example, GPS receivers combined with cellular phone modems can be activated automatically in an accident or manually by motorists to summon help for breakdowns, fires, medical emergencies, accidents, criminal threats, or other emergencies. Digital maps are important in the dispatch center to determine the location of the emergency from the remote GPS position and to provide the most effective response. Automotive navigation systems and map displays in the responding vehicles can show the precise location of the emergency relative to the responders' locations and can thereby enhance the speed and reliability of the response.

Database Requirements For Its Applications

The discussion above indicates that the ITS importance of various geographic-database attributes depends on the specific requirements of each ITS function. These dependencies are illustrated by Table 1. The ITS functions shown in the table are not necessarily independent of one another. Most can be used in conjunction with others. For example, real-time information can be used with all of the other functions shown in the table. Pathfinding and route guidance can be used with all of the other functions except vector navigation.

The basic digital road map database is very important to all applications except vector navigation which depends only on the latitudes and longitudes of the origin and destination. Road classification is very important to all applications that involve zooming of map displays, as well as those that involve pathfinding. Positional accuracy of the map and/or the directory listings is very important to navigation, route guidance, fleet management and mayday applications because of the importance of knowing the precise locations of vehicles and destinations. A 100 meter error can put a vehicle, destination, or incident on the wrong block or on a frontage road instead of a freeway. Such mistakes can result in dispatching the wrong vehicle, taking an indirect route, or going to the wrong destination.

Complete and accurate addresses and business directories are very important for all ITS applications that involve selection of destinations. Travel and tourist guides are very important to traveler information systems including automotive navigation systems. They are also very important in fleet management applications because businesses, tourist attractions, and landmarks are often known by their names rather than their addresses.

Connectivity, directionality, and turn restrictions are essential to pathfinding and route guidance applications. They are also important to fleet management operations and useful to Mayday operations, but not essential in either case. Signage information is useful so that route guidance and dispatch instructions agree with freeway signage.

Database compactness and speed of access are important for all ITS applications, especially since many ITS products have modest processors with limited storage capacities.

Its Database Quality Requirements

The success and effectiveness of various ITS products and services fundamentally depend on the accuracy and completeness of their geographic databases. But imperfections in some attributes can have far more serious consequences than those in others. For example, if particular restaurants were missing from a restaurant guide, users would notice but not be terribly concerned. If some addresses were missing from the address index, users would be mildly annoyed but could compensate by entering a nearby cross street. If streets were missing from a map users would become increasingly annoyed particularly if their home or business happened to be on that street or if it were a street that they drove on regularly. If connectivity

were incorrect so that roads did not connect as indicated on the map, drivers could become frustrated. Or if errors in directory listing locations led them to wrong destinations, drivers could become very frustrated indeed. All such imperfections could have a negative impacts on the market acceptance of ITS products and services.

But the most critical database quality issues involve pathfinding and route guidance where, if directionality and turn restrictions are incorrect, drivers may be guided to illegal turns or to turning the wrong way onto a one-way street. In such cases database errors could have serious safety and liability impacts. Ultimately, drivers should be responsible for assuring that any maneuvers they make are safe and legal, but it seems inevitable that some accidents will eventually be blamed on route-guidance devices with resulting liability claims. To minimize such risks, it is especially crucial that route guidance attributes be virtually error free. Accuracy of the other attributes is important, but accuracy of route guidance attributes seems paramount.

CONCLUSIONS

The accuracies required for ITS navigation and routing depend upon the specific application, but a variety of techniques are available that permit cost performance tradeoffs to meet a wide range of applications. There does not appear to be a single technology that can adequately perform in-vehicle navigation and map display by itself. However, there are many combinations of technologies that can provide adequate to outstanding performance. It appears that dead reckoning is a necessary component of most in-vehicle navigation applications, and map-matching is desirable in most applications and especially in remote areas when differential GPS is unavailable.

Geographic databases in the forms of digital maps and digital directories are serving fundamental and crucial functions in navigation, routing, and other ITS applications. They serve particularly critical roles in fleet management, emergency notification (Mayday), and traveler information systems (including navigation, destination determination, pathfinding, routing and real-time information presentation). The efficacy and market success of many ITS products and services will depend on the accuracy and completeness of their geographic databases. Safety and liability concerns make database accuracy especially critical for route-guidance systems.

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Table 1
Geographic Database Attribute Requirements for ITS Applications
(Key: ○ = Useful; ◗ = Important; ● = Very Important)

Database Attribute	ITS Function						
	Vector navigation	Nav with map display	Traveler information	Real-time information	Pathfinding & guidance	Fleet management	Mayday
Basic road map		●	●	●	●	●	●
Road classification		●	●	●	●	●	●
Positional accuracy	●	●	○	◗	●	●	●
Addresses	●	●	●		●	●	○
Landmarks	●	◗	●	○	◗	◗	○
Directories	●	●	●	○	●	●	○
Connectivity					●	◗	○
Directionality		○			●	◗	○
Turn restrictions					●	◗	○
Signage					○	○	
Compactness	◗	◗	◗	◗	◗	◗	◗
Data access speed	◗	◗	◗	◗	◗	◗	◗